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EVALUATION OF CONTROL STRATEGIES FOR BUS PREEMPTION OF TRAFFIC SIGNALS

FINAL REPORT

BY

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16. Abstract

An algorithm which allows signal preemption by buses was developed for the NETSIM model. It was programmed into this model by FHWA. Subsequently, this algorithm was tested by comparing the results generated by the NETSIM model with results obtained from a manual implementation of bus preemption at one intersection in the field.

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Summary

Signal preemption by buses has been used more and more in recent years as a means of improving passenger flow through an intersection or arterial. Although bus priority will decrease delay to the preempting approach, for an overall improvement to be realized, this savings in delay must offset the increase in any delay to the other approaches. Thus, some method of estimating the consequences to the total network of implementing bus signal preemption is necessary. For this reason, NJDOT has developed a bus signal preemption algorithm for programming into the NETSIM simulation model. This algorithm implements bus signal preemption by advancing or extending green while still maintaining a minimum side street green. The algorithm was programmed into the NETSIM model by FHWA and was tested by comparing the results obtained from NETSIM with results obtained from a manual implementation of bus signal preemption at one intersection in the field.

Based on the testing done, the algorithm is felt to be a reliable estimator of the consequences of implementing bus signal preemption at an intersection or on an arterial in the field.

Introduction

In recent years, the trend in transportation has been away from increasing highway capacity by expanding the highway system in favor of increasing highway capacity by increasing the efficiency of the existing system. This efficiency is normally measured in terms of the number of vehicles which can be moved through the system in a given period of time. However, recently because of the need for energy conservation, an increased emphasis has been put on the number of vehicle passengers moved as well.

One of the ways in which the efficiency of a highway can be increased particularly in regard to passengers, is through use of bus preemption at signalized intersections.

Preemption allows a bus to travel through a signal with reduced delay by causing the signal to allocate additional green time to the direction in which the bus is traveling. Control strategies which had been used to implement the preemption had included varying signal phase lengths, changing phase sequences or adding phases. Implementation of bus preemption at a signalized intersection, naturally, results in decreased passenger delay in the direction of bus travel. However, delays and interruptions of traffic on the preempted approaches could outweigh any advantage gained from reduced passenger delay on the favored approaches. This effect would not be apparent until after operation has begun.

As an aid to implementation of bus preemption, a means of evaluating the effect on total passenger delay of applying a particular control strategy at a particular traffic signal should be developed. This would allow the traffic engineer to obtain knowledge of the results of such an operation without committing to actual implementation with its large purchase and installation costs.

Study Procedures

A. Study Scope

The original objective of this project was to develop a method for determining the effect on person delay, at signalized intersections, of several bus preemption control strategies. Once this method had been developed and validated, it would be used to determine the strategy which would minimize person-hours of delay when implemented on a selected arterial in the field. Toward this end, five bus preemption strategies were selected for comparison. These five preemption strategies were:

1. to advance or extend green while maintaining a minimum cross street green;
2. to advance or extend green without maintaining a minimum cross street green (this would allow the controller to skip a phase);
3. to use the bus TRANSYT method of optimizing a synchronized signal system (bus TRANSYT allows optimization for passenger delay instead of vehicle delay);
4. to advance or extend green while compensating the cross street in subsequent phases; and
5. to insert a phase for left turning buses (this too would include compensation).

An algorithm for each of these five strategies was developed. These algorithms, in turn, were to be used as a means of incorporating the strategies into the NETSIM simulation model. After this incorporation had been completed by the staff of the FHWA, the five strategies were to be validated by comparing the simulated output with the results of a study implementing these strategies in the field. Once these algorithms had been validated, they were to be used to determine the best strategy for use in implementing a bus preemption system on a particular arterial in New Jersey.

Due to various factors beyond the control of this project, the scope had to be reduced. One of these factors was the inability of FHWA, due to budgetary and manpower problems, to complete incorporation of the five algorithms into the NETSIM model. Another factor was the demise of a proposed UTCS system on the arterial chosen for implementation of a bus preemption system.

Although the original objectives of this project cannot be accomplished because of the aforementioned problems, the algorithms which have been incorporated into the NETSIM model still represent a good method for predicting the effect on total intersection passenger delay of implementing bus preemption at a signalized intersection. For this reason, it was decided that a new and more reasonable objective under the circumstances would be the development, testing and validation in the field of those algorithms which had been incorporated into the NETSIM model.

B. Development of Bus Preemption Simulation Algorithms

The five control strategies chosen for comparison were selected to provide a wide range of alternatives. They range from Strategies 1 and 2, which were developed for use with any type of controller to Strategies 4 and 5, which require computerized control of the intersection for implementation. Strategy 3, although included with the other control strategies, does not require an active preemption. Rather, it uses the TRANSYT optimization model to develop a system of offsets and phase splits which minimizes person delay rather than vehicle delay.

In order for FHWA to incorporate the control strategies into the NETSIM model, it was necessary that an algorithm for each strategy be developed. This algorithm would indicate the procedure by which the control strategy was to be called, the method of implementing the control strategy and any limitations or minimums put on the functioning of the control strategy. In its final form, the

algorithm consisted of a series of flow charts depicting the various subroutines which make up the algorithm, along with documentation explaining the function of each of these subroutines. The algorithm for Strategy 1, which was the only one eventually incorporated into the NETSIM model, along with its documentation and detector location diagrams (Figures 4 and 5) can be seen in Appendix A.

Strategy 1, which represents the least complex form of preemption, allows a bus arriving at the intersection in red to preempt the signal while still maintaining a cross street green phase. The arriving bus can obtain preemption in the form of either green extension or green advance. Safeguards have been built into the algorithm to avoid a "green flash" condition during a preempted cycle.

Two variations of Strategy 1 were incorporated into the NETSIM model -- one for use at intersections with a near side (of the intersection) bus stop, and the other for use at intersections with a far side bus stop. Essentially, the only difference between these two variations is the presence of an additional detector at the stop line of the intersection. This allows a near side stopping bus some additional green time to pass through the intersection if the maximum preemption time has not been reached during the current cycle. Since the bus preemption implementation program in NETSIM defines which strategy variation is to be used by node (intersection) rather than by individual link (approach), all bus stops on any approach to the intersection must be of the same type (near side or far side) if preemption of the signal by buses is to be simulated by the NETSIM model.

Although differing in the presence or absence of an additional third detector at the intersection stop line, both variations of Strategy 1, as developed and programmed into NETSIM, are similar in their use of the two upstream detectors. The farthest upstream detector (Detector 1) only calls for a

preemption if an exogenously set congestion time limit expires before the announced bus reaches the primary detector (Detector 2). Otherwise, the primary detector will call for the preemption. This is to assure that congestion on the approach does not prevent the approaching bus from gaining the benefits of the signal preemption system.

The additional third detector, located at the signal stop line in the case of a near side bus stop, is only used if the maximum allowable preemption time has not expired. If preemption time is still available, this detector will grant additional time for passage through the intersection to a bus which has become trapped because of stopping to take on or discharge passengers. If the maximum allowable preemption time has expired, however, no additional time can or will be granted.

Another feature of the algorithm developed for Strategy 1 is the ability to disallow preemption on a cycle immediately following a preempted cycle. This feature was included to minimize as much as possible the deleterious effects to the cross street during preemption which would be caused by heavy bus flows.

The algorithm for Strategy 1 was not designed with any particular bus detection system in mind so as to increase its flexibility. In this way, a choice of detection system need not be made in order for the NETSIM simulation to be used in ascertaining the effect of bus preemption on an intersection or arterial. The input procedures and cards necessary to initiate this algorithm within the NETSIM model are included as Appendix B.

After the algorithm for Strategy 1 had been developed and programmed into the NETSIM model, it was subsequently tested by comparing the results of the simulation with the results of a study in which preemption of a signalized intersection by buses was implemented manually in the field.

Field Study

Once modification of the NETSIM model to include the algorithm for Strategy 1 had been completed, it was necessary to test the results obtained from this modification. To this end, it was decided to compare the simulation results with results obtained from a study of bus preemption conducted at a signalized intersection in the field.

Because of the large number of personnel required for data collection and the problems of coordination inherent in conducting bus preemption manually at more than one intersection, it was decided to limit the field study to one signalized intersection. The following criteria were used to develop a list of candidate intersections for this study:

1) The signal controller at the intersection should be a 2-Ø controller.
2) The cross street green should be capable of being reduced while still allowing pedestrian clearance.
3) There should be between 10 and 25 buses per hour during the peak hour.
4) The bus stops should be located on the far side of the intersection, if possible.
5) There should be minimal pedestrian traffic.

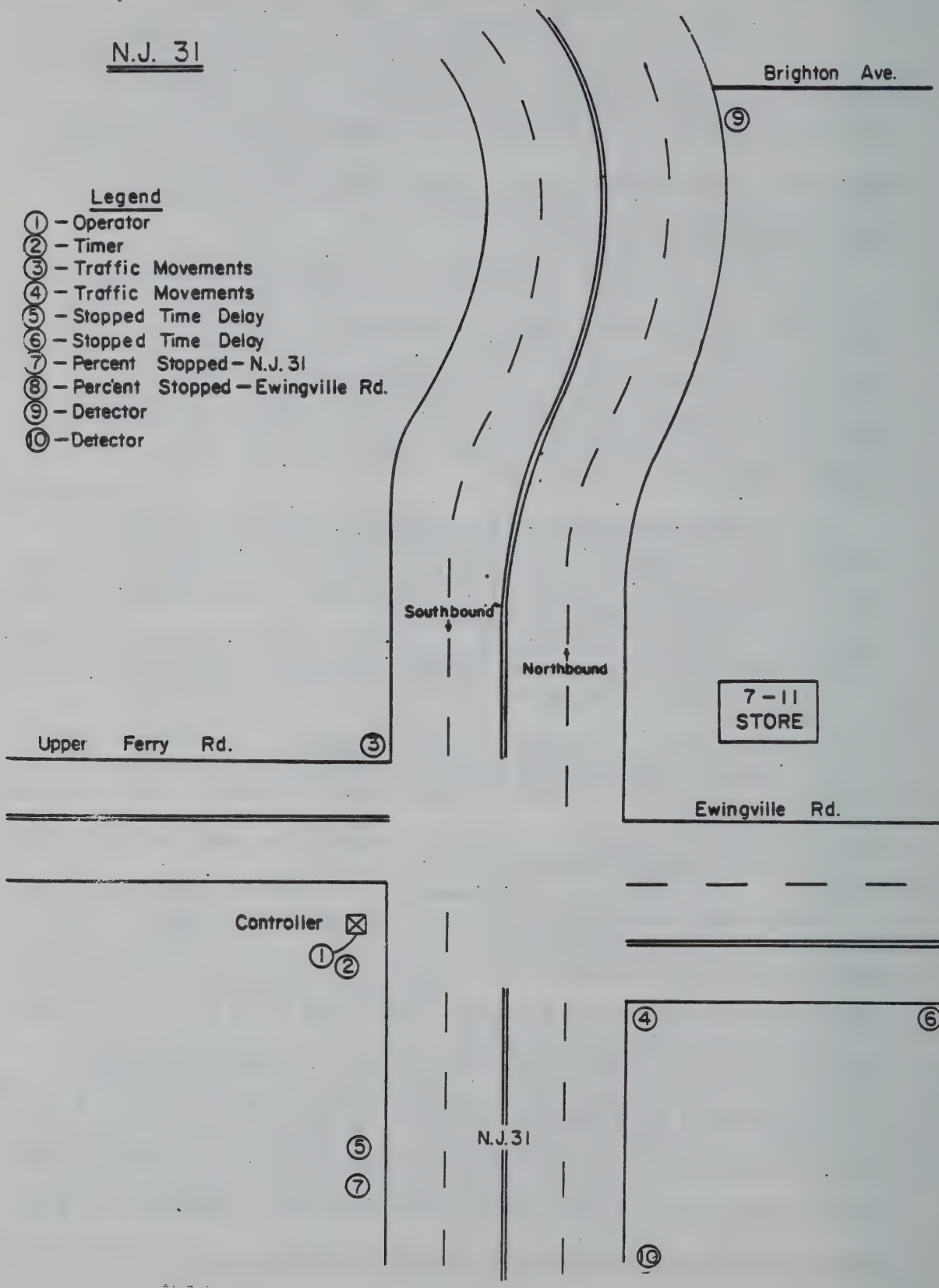
Using these criteria, various sites were screened for suitability. The list of candidate intersections was narrowed to seven, and after some further study, the intersection of Route 31 and Ewingville Road-Upper Ferry Road near Trenton was chosen as the site where the field study would be conducted (see Figure 1).

The Route 31 and Ewingville Road intersection is controlled by a 2-Ø semi-actuated signal with a 70 second background cycle. The Ewingville Road approach, which is the actuated phase, experiences heavy congestion during the evening peak hour. The Route 31 approach, although not quite as heavily

FIGURE 1

FIELD STUDY

NJ 31 AND EWINGVILLE ROAD



congested, still experiences long queues which tend to inhibit bus passage through the intersection.

Two bus routes go through this intersection during the day at half hour headways. These two are joined by a third route also at half hour headways during the peak hour. All bus stops at this location are on the far side.

Although the three bus routes that go through this intersection all run on half hour headways, the nature of these routes is such that bus arrivals are dispersed over the entire peak hour. This dispersion permits implementation of the policy of disallowing preemption of the signal on the succeeding cycle after a preempted cycle without adversely affecting any of the bus routes.

The algorithm for Strategy 1 as programmed into the NETSIM model used in-street detectors as a means of sending a call for preemption of the traffic signal. Once this call is received, the algorithm checks the current condition of the signal to determine how the bus priority should be accomplished. In order to simulate the action of this algorithm in the field it was necessary to have a person manually actuate the traffic signal when a call for preemption was received. A person with a walkie-talkie located approximately 600 feet upstream from the intersection, served as the detector. When a bus arrived at the "detector" location, it would be called in to the signal operator who was located at the intersection. This allowed the signal operator sufficient time to determine the form of preemption to be given. The manual operator could accomplish the bus priority either by advancing the green interval if a bus approached during the red interval, or by extending the green interval enough to get the bus through if it approached at the end of this interval and might otherwise be caught at the beginning of the red interval. However, if a green advance was called for, the signal operator was required to allow the cross street a minimum green interval of 12 seconds before the green advance could begin, in order to prevent a "green flash" condition from occurring on the crossroad.

The signal timing plan used during the preemption cycles was designed to stay within the range of the normal activity of semi-actuated control at the intersection. Particular attention was paid to the clearance intervals to assure that they were not shortened in any way during the periods of manual operation. During cycles when no call for preemption was received or when sufficient time existed for the bus to proceed normally through the intersection without preemption, the signal was left on automatic control. The authorized signal timing plan for semi-actuated control in effect during the time when the field study was conducted is documented by Appendix C. Appendix C also documents the instruction sheets provided to both the signal operator and the signal timer, as well as the signal timing plan used for preempted cycles.

The field study in which Strategy 1 was implemented was conducted between the hours of 4 and 5 p.m. which corresponds to the evening peak hour at Route 31 and Ewingville Road. A follow-up study with no signal preemption was conducted at the same time the next day. During these studies, traffic volumes and turning movements were counted for all four approaches. In addition, stopped time delay for all vehicles and the percent of vehicles which stopped at least once were measured for the two more heavily congested approaches (Ewingville Road and Route 31 NB). The beginning of each green interval and the beginning and end of all clearance intervals were recorded on tape at the time the two field studies were being conducted. These tapes were later transcribed to obtain the actual signal splits used during each cycle. Also recorded on tape was the beginning and end of each period of manual operation of the signal.

Traffic movements and signal timing data collected during the field studies along with the intersection geometry were used as input to the NETSIM model in order to assure the comparability of the field results with results obtained from

the NETSIM simulation. The measures of effectiveness used as a means of comparison between the field results and simulation results for this analysis were stopped time delay and the percent of vehicles which stop at least once.

Results

In evaluating the performance of the bus preemption algorithm, two measures of effectiveness (MOE) were used. These were: (1) average delay per vehicle and (2) percent of vehicles stopping. The MOE's were compared for three different situations: (1) field (with bus preemption) versus simulated (with bus preemption), (2) field (without bus preemption) versus simulated (without bus preemption), and (3) simulated (with bus preemption) versus simulated (without bus preemption). The first situation is a straight forward comparison of the data collected while implementing the algorithm in the field with the data generated by the NETSIM model using the bus preemption subprogram. The second situation compares data collected in the field on a different day when preemption was not implemented, with data generated by the NETSIM model. This second situation acts as a control since the preemption subprogram was not used in generating the NETSIM data. The third situation compared data generated by the NETSIM model using the preemption subprogram with data generated without the use of the preemption subprogram for the same conditions. This comparison is meant to show the benefits or disbenefits of implementing signal preemption by buses at a particular site.

The data from the first two situations was subject to both the Wilcoxon test and the student-t test. The Wilcoxon test was used for reason of the small amount of data points (12) as well as for reason of the presence of matched pair data to which this test lends itself. The results of these tests for the first two situations can be seen in Tables 1 and 2, respectively.

In the case of situation 1 (field using bus preemption versus simulated using bus preemption), the t-test found no significant difference bvetween the two data sets for both MOE's at the 95% level. This was also the result with the Wilcoxon test. Although the range of confidence at the 95% level for the

TABLE I

RESULTS OF WILCOXON & t - TESTS

FOR SITUATION I (PREEMPTION)

TIME	FIELD		SIMULATION		DIFFERENCE		TEST RESULTS	
	DELAY (SECS.)	PCT. STOPPED	DELAY (SECS.)	PCT. STOPPED	DELAY (SECS.)	PCT. STOPPED	DELAY (SECS.)	PCT. STOPPED
RT. 31 NB.								
4:00 – 4:10	5.7	33	12.1	39	+6.4	+6	WILCOXON	WILCOXON
4:10 – 4:20	9.0	44	14.7.	47	+5.7	+3	For N = 12, Value of T	For N = 11, Value of T
4:20 – 4:30	8.6	42	14.7	47	+6.1	+5	ranges from 14 – 64 for	ranges from 11 – 55 for
4:30 – 4:40	18.4	58	15.0	46	-3.4	-12	α = .052	α = .054
4:40 – 4:50	14.0	54	15.2	46	-1.2	-8	T = 39	T = 31
4:50 – 5:00	5.5	24	15.1	46	+9.6	+22	∴ accept Ho	∴ accept Ho
EWINGVILLE RD.								
							T – TEST	T – TEST
4:00 – 4:10	21.3	88	21.4	78	+0.1	-10		
							N = 12	N = 12
4:10 – 4:20	29.8	76	21.5	75	-8.3	- 1	$t_{.025,11} = 2.2$	$t_{.025,11} = 2.2$
4:20 – 4:30	29.6	87	23.1	78	-6.5	-9		
							S = 23.2	S = 9.6
4:30 – 4:40	47.9	89	41.7	97	-6.2	+ 8	t = 0.86	t = 0.15
4:40 – 4:50	90.8	100	81.0	100	-9.8	0	∴ accept Ho	∴ accept Ho
4:50 – 5:00	51.7	99	128.1	100	+76.4	+ 1		

TABLE 2

RESULTS OF WILCOXON & t - TESTS FOR
SITUATION 2 (NO PREEMPTION)

TIME	FIELD		SIMULATION		DIFFERENCE		TEST RESULTS	
	DELAY (SECS.)	PCT. STOPPED	DELAY (SECS.)	PCT. STOPPED	DELAY (SECS.)	PCT. STOPPED	DELAY (SECS.)	PCT. STOPPED
RT. 31 NB.								
4:00 - 4:10	7.1	45	16.0	45	+8.9	0	WILCOXON	WILCOXON
4:10 - 4:20	8.0	46	16.5	48	+8.5	+ 2	For N = 12, Value of T	For N = 11, Value of T
4:20 - 4:30	6.8	32	16.8	49	+10.0	+17	ranges from 14 - 64 for	ranges from 11 - 55 for
4:30 - 4:40	7.1	42	17.5	50	+10.4	+ 8	α = 0.052	α = 0.054
4:40 - 4:50	8.8	48	17.8	50	+9.0	+ 2	T = 50	T = 30
4:50 - 5:00	5.9	33	17.7	51	+11.8	+18	∴ accept Ho	∴ accept Ho
EWINGVILLE RD.								
							T- TEST	T-TEST
4:00 - 4:10	15.8	77	21.5	65	+5.7	-12		
							N = 12	N = 12
4:10 - 4:20	26.5	80	21.5	73	-5.0	- 7	$t_{.025,11}$ = ±2.2	$t_{.025,11}$ = ±2.2
4:20 - 4:30	24.9	85	25.0	74	+0.1	-11		
							S = 16.4	S = 12
4:30 - 4:40	29.3	78	27.9	79	-1.4	+ 1	t = -0.11	t = -0.4
4:40 - 4:50	76.6	100	32.6	83	-44.0	-17	∴ accept Ho	∴ accept Ho
4:50 - 5:00	50.3	99	30.4	81	-19.9	-18		

difference is rather large ($\pm$51.0 seconds for delay and $\pm$21% for percent stopped), the average absolute difference for the 12 points sampled is only $\pm$11.6 seconds of delay and $\pm$7.1%.

For situation 2 (field without bus preemption versus simulated without bus preemption), both the t-test and the Wilcoxon test found no significant difference between the two data sets at the 95% level. The range of confidence at the 95% level for this situation is $\pm$36.1 seconds and $\pm$26.4% for vehicle delay and percent stopped, respectively. The average absolute difference for the 12 sample points is $\pm$11.2 seconds and $\pm$9.4% for vehicle delay and percent stopped, respectively. Because the preemption subprogram can only be used with fixed time signal control, it was necessary in coding the NETSIM simulation to use the signal timing initiated for a cycle where the Ewingville green has maxed out. Since during the peak hour at the study site (Route 31 and Ewingville Road) the Ewingville Road phase almost always goes to maximum green, this did not cause a problem in comparing the field simulation data sets.

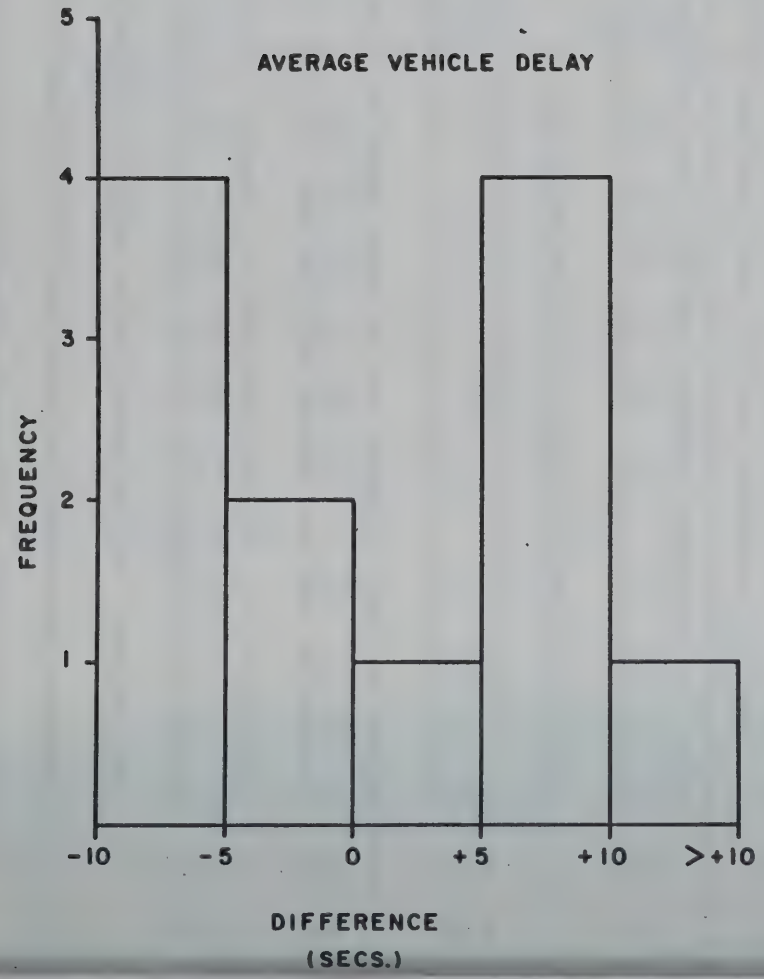
In both situations, the MOE data generated by the NETSIM model was found to adequately estimate the MOE data collected in the field. The frequency distributions for situations 1 & 2 for average vehicle delay and percent stopped are shown as Figures 2 and 3, respectively.

The final situation (simulated with bus preemption versus simulated without bus preemption) is indicative of how the bus preemption algorithm can best be put to use. It shows for the same input data the condition of the test intersection with and without implementation of a bus preemption strategy. In the case of the study intersection, the results of this comparison showed a savings of 6.2 vehicle hours during the peak hour if signal preemption by buses is implemented. This translates into a savings of 8.7 seconds per vehicle. Total passenger hours saved (using average vehicle occupancy of 1.2 and average bus occupancy of 40) is 9.2 passenger hours over the one hour peak hour period.

FIGURE 2

SITUATION I (PREEMPTION)

FREQUENCY DISTRIBUTION FOR MOE'S



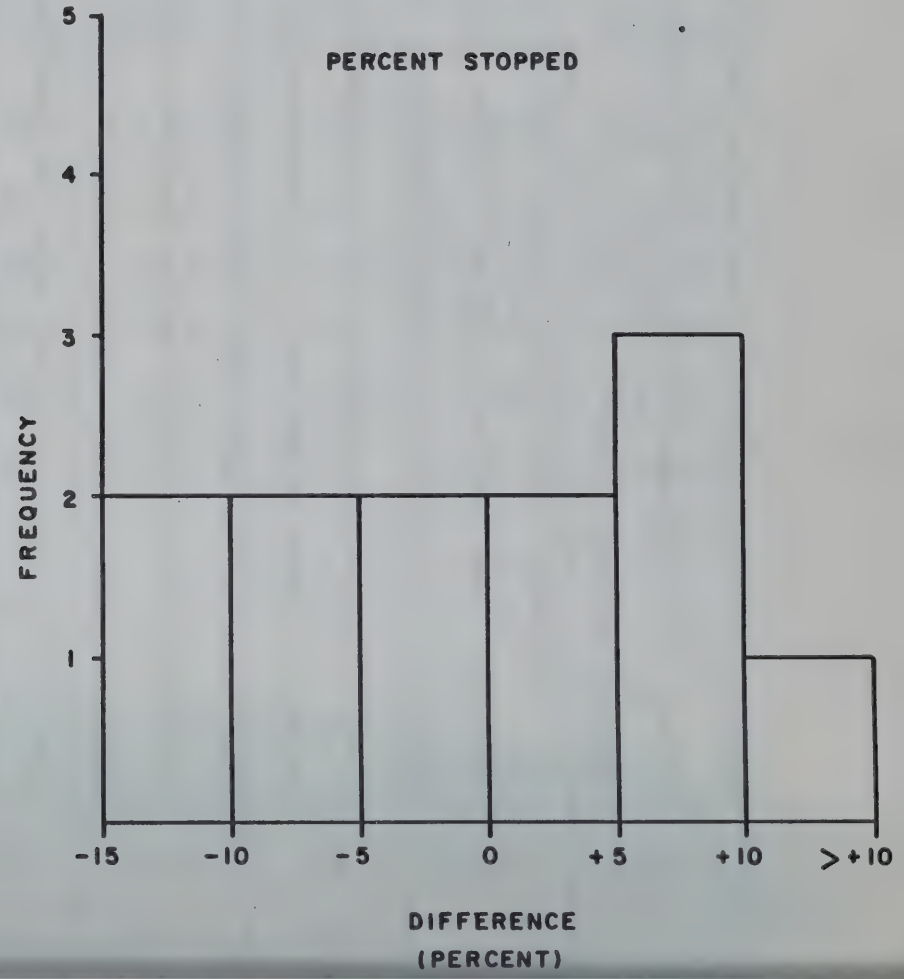
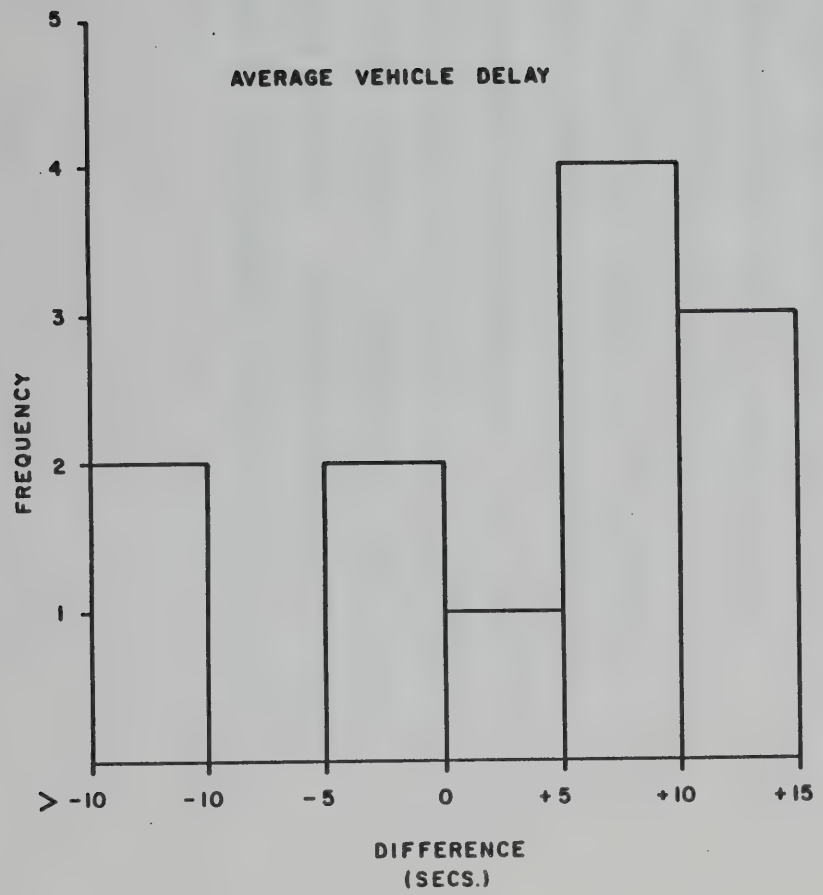
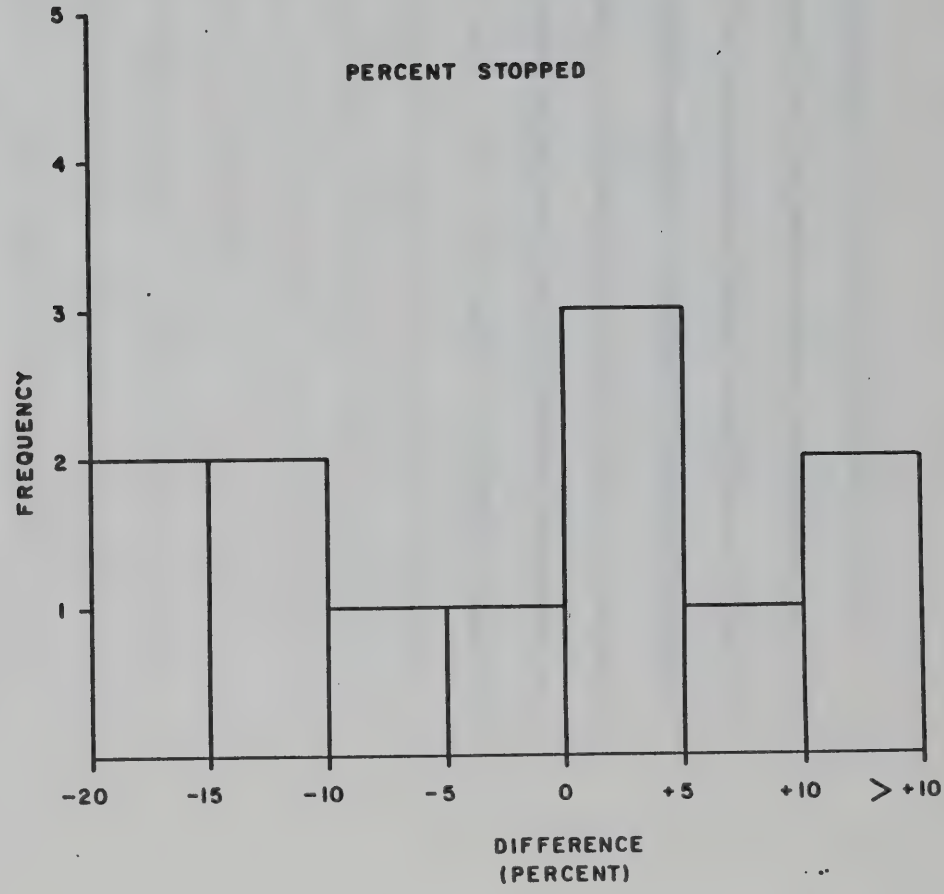


FIGURE 3

SITUATION 2 (NO PREEMPTION)

FREQUENCY DISTRIBUTION FOR MOE'S





Using these results, the traffic engineer can determine if the estimated savings is sufficient to offset the cost of installing a bus signal preemption system. In reality, bus signal preemption would be implemented on an entire arterial or network rather than at one intersection. Since NETSIM can also be used to simulated an arterial or network this would cause no problem However, the comparison should then be made for the entire system rather than just for individual intersections within it.

Conclusions and Recommendations

Originally, five bus preemption strategies had been chosen for comparison. However, the aforementioned budgetary and manpower problems experienced by FHWA reduced this to one. Fortunately, this strategy (which advances or extends green while maintaining a minimum cross street green) is the most widely used and implementable of the group. The algorithm for this strategy was programmed into the NETSIM model. This algorithm was tested by comparing the results of the NETSIM model with results obtained by manual implementation of bus signal preemption in the field. This was done through use of both the Wilcoxon signed-ranked test and the t-test. Both tests found no significant difference between the two data sets at the 95% level.

Although more testing should be done, it is felt that the bus preemption algorithm as presently programmed into the NETSIM simulation model is a fairly reliable indicator of the effects of a bus signal preemption operation on an intersection in the field. As such, it satisfies the original objective of this study which was to provide a means of looking at the consequences to an intersection of implementing bus signal preemption without actually installing equipment.

It is recommended that further testing of this algorithm be done, particularly if possible at an intersection where a bus signal preemption operation has already been installed. It is also recommended that bus signal preemption itself be considered as a viable alternative in alleviating some of the congestion problems in this state. Further research should also be made into different means of implementing bus signal preemption, particularly in regard to the Passive Bus Detector developed by FHWA. This device would alleviate the operating agency of the necessity of instrumenting all buses in order to assure that they receive priority.

APPENDIX A

STRATEGY 1

ALGORITHM

AND

DOCUMENTATION

BUS PREEMPTION LOGIC
STRATEGY 1a - FAR SIDE - COMPUTERIZED CONTROL
(FLOW CHART ROUTINES A, C & D; FIGURE 4)

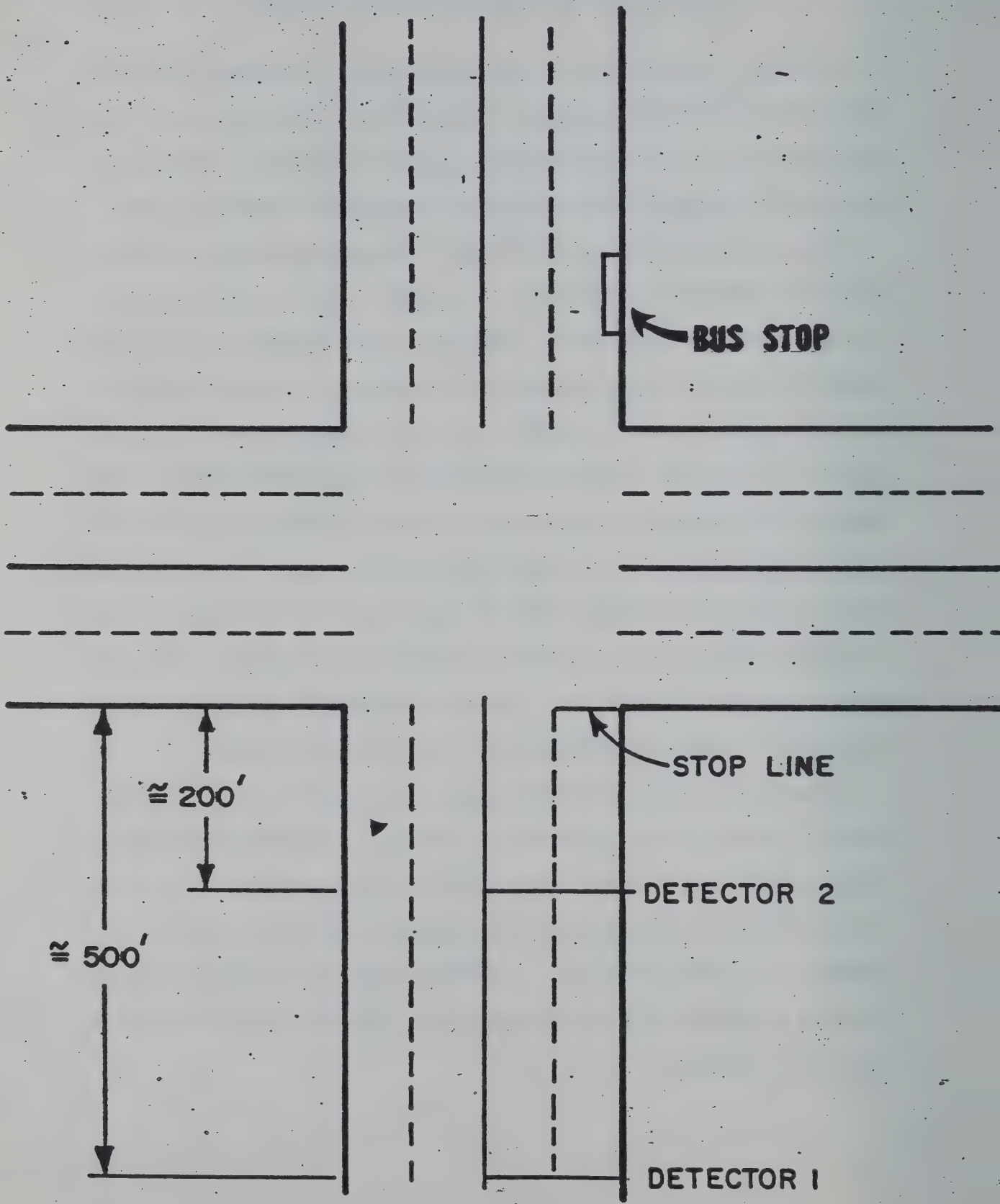
Strategy 1 provides for a bus to either extend or advance green on a particular street while maintaining a minimum cross street green as well as a background cycle. Since a farside bus stop is under consideration in Strategy 1a, variations in bus travel times due to bus pickup and delivery are not considered.

Two detectors are used in this strategy. The upstream detector (Detector 1) does not preempt under normal traffic conditions. It only preempts if traffic is queued to an extent that the bus is delayed in traffic upstream of the second detector (Detector 2). Thus, if Detector 1 is actuated by a bus and Detector 2 is not actuated within some reasonable time limit (congestion time limit) preemption will take place. The length of preemption will be determined from when the bus crosses Detector 2. If the bus does not reach Detector 2 within the same cycle in which Detector 1 is actuated, then the full preemption time will be used. If Detector 2 is actuated within the same cycle, then an additional fixed bus clearance interval will be provided. If and when the maximum preemption time is completely used in this latter case, preemption will terminate and preemption in the following cycle will not be caused by the same bus.

Under normal traffic conditions, when the queue allows the bus to reach Detector 2 under free flow, Detector 2 will preempt. A fixed clearance interval will be provided for Detector 2 preemption under green extension. For green advance, minimum side street green is maintained and then a minimum preemption of 15 seconds is given. A minimum green of 12 seconds with an additional 3 seconds amber is maintained on all approaches in order to avoid a "green flash" condition.

FIGURE 4

DETECTOR LOCATIONS – FAR SIDE BUS STOP



ROUTINE A

If consecutive preemptions have occurred in N cycles, then preemption will take place in the N + 1 cycle. Detector 1 and Detector 2 are both checked for actuation. If Detector 1 is actuated and Detector 2 is not actuated within some time limit (congestion time limit), then it will be assumed that the bus is delayed in traffic. When the time limit is exceeded, preemption takes place (Routine D).

Detector 2, when actuated, will always provide a preemption (Routine C). If Detector 1 actuation plus the congestion time limit results in a preemption and if the bus has not crossed Detector 2, during the maximum allotted preemption interval, then the actuation of Detector 2 will cause an additional preemption for the same bus in the following cycle. If Detector 1 is actuated but Detector 2 is actuated with the congestion time limit, then preemption will take place from Detector 2.

ROUTINE C

Routine C is a normal preemption called from Detector 2. It determines if the approaching bus will get preemption in either the form of a green extension or a green advance. In the logic for green advance, in this routine, and in all others, a minimum green of 12 seconds plus 3 seconds amber is required by NJDOT policy on any approach to avoid a "green flash" condition.

ROUTINE D

Routine D is only used when the congestion time limit is exceeded. As in Routine C, it first determines if the bus will get a green extension or green advance. In the green extension, preemption can be extended to the maximum allowable preemption while still maintaining a minimum 15 second phase for the cross street. In green advance, the maximum preemption will continue into the green of the following cycle.

BUS PREEMPTION LOGIC

STRATEGY 1b - NEAR SIDE BUS STOP - COMPUTERIZED CONTROL (FLOW CHART ROUTINES B, E, F AND G; FIGURE 5)

Strategy 1 provides for a bus to either extend or advance green on a particular street while maintaining a minimum cross street green as well as a background cycle. Since a near side bus stop is under consideration in Strategy 1b, variations in bus travel times due to bus pick-up and delivery are considered.

The operation and interaction for the two upstream detectors (Detectors 1 and 2) in Strategy 1B is the same as that for Strategy 1a. The difference between the two strategies is the presence of a third detector (Detector 3) located just downsteam of the near side bus stop. Detector 3 provides a "short preemption" to allow a stopping bus which has lost its first preemption to obtain a second one upon departure. The minimum side street green is maintained for the same duration as in Strategy 1a.

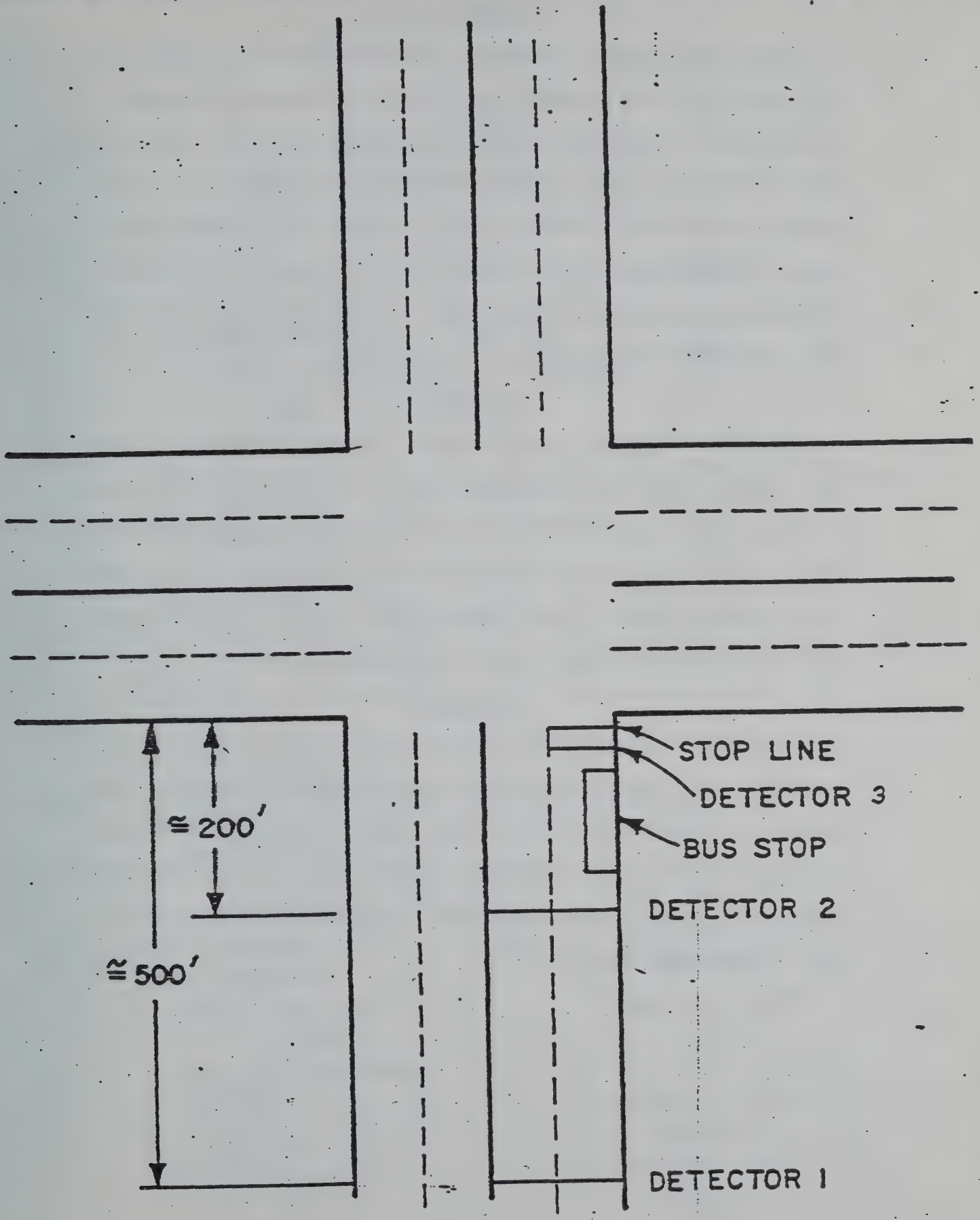
ROUTINE B

If consecutive preemptions have occurred in N cycles, then preemption will not take place in the N + 1 cycle. Detectors 1, 2 and 3 are all checked for actuation. If Detector 1 is actuated and Detector 2 is not actuated within some time limit (congestion time limit), then it will be assumed that the bus is delayed in traffic. When the time limit is exceeded, preemption takes place (Routine G).

Detector 2, when actuated, will always provide a preemption (Routine E). If Detector 1 actuation plus the congestion time limit results in a preemption and if the bus has not crossed Detector 2 during the maximum allotted preemption interval, then the actuation of Detector 2 will cause an additional preemption for the same bus in the following cycle. If the Detector 1 is actuated but Detector 2 is actuated within the congestion time limit, then preemption will take place from Detector 2.

FIGURE 5

DETECTOR LOCATIONS – NEAR SIDE BUS STOP



ROUTINE E

Routine E is a normal preemption called from Detector 2. If time for a "long preemption" is not available, then Detector 3 is checked for actuation. It is determined if the approaching bus will get preemption in either the form of a green extension or a green advance. In the logic for green advance in this routine and in all others, a minimum green of 12 seconds plus 3 seconds amber is required by NJDOT policy on any approach to avoid a "green flash" condition. If sufficient time is available and if no further calls for preemption are received, green is returned to the side street.

ROUTINE F

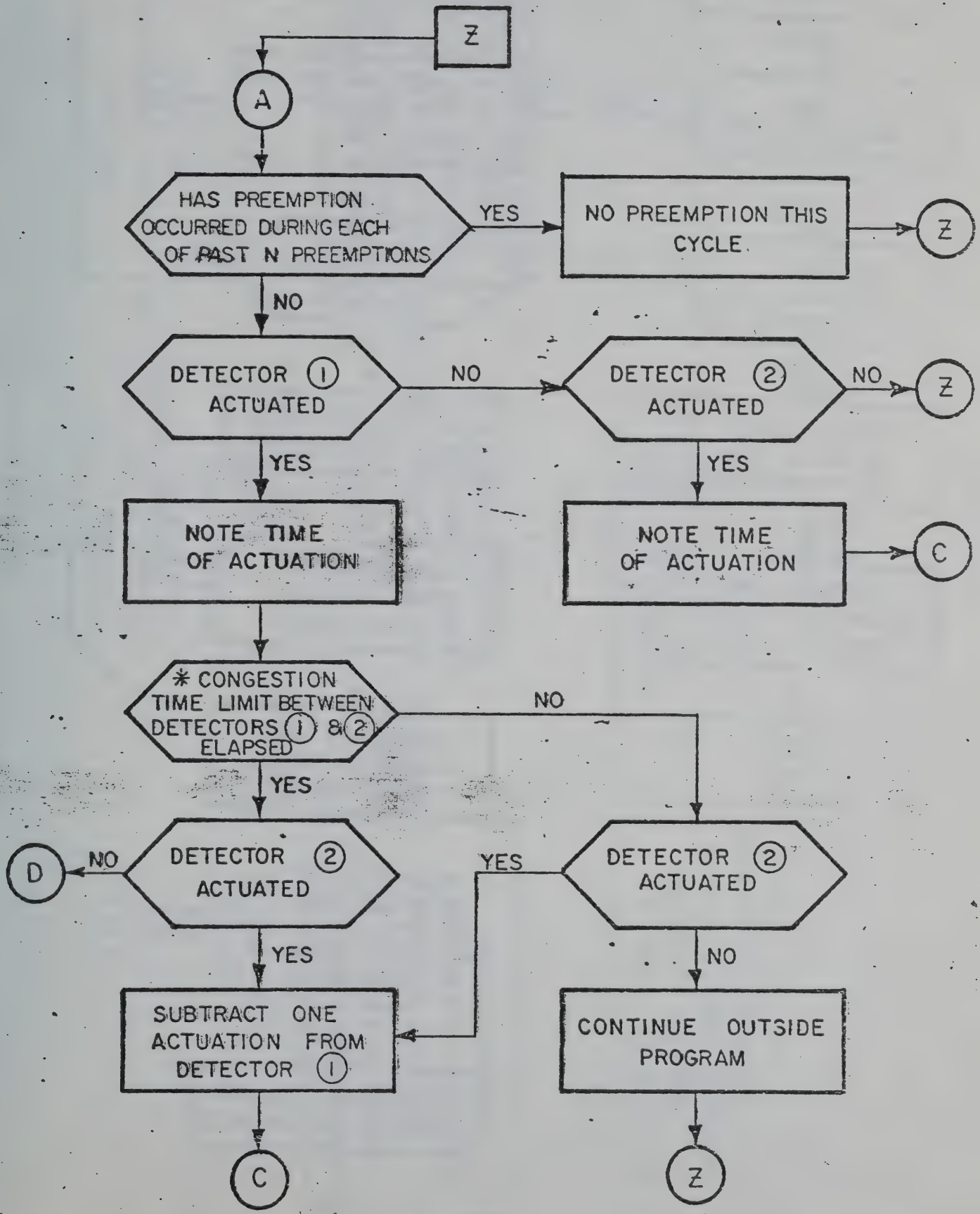
Routine F is designed to accommodate a bus using a near side bus stop. The bus detector (Detector 3) is located in the curb side lane only. Thus, a bus on the approach can actuate Detectors 1 and 2, but not necessarily Detector 3. Detector 3 can preempt either in an extension or advance mode. In the advance mode, provision is made to ensure against "green flash" by maintaining main street green if cross street green is below a minimum time.

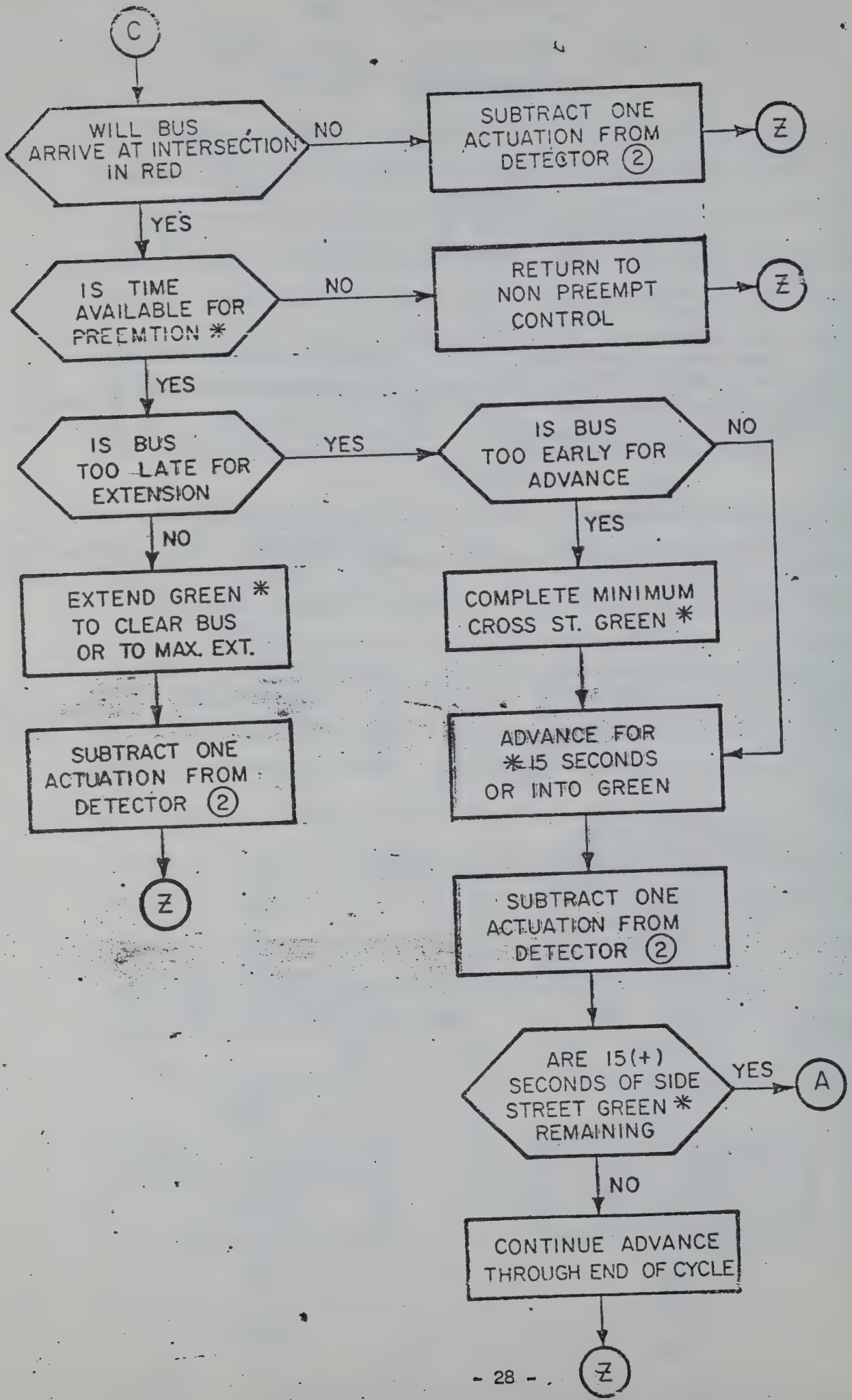
ROUTINE G

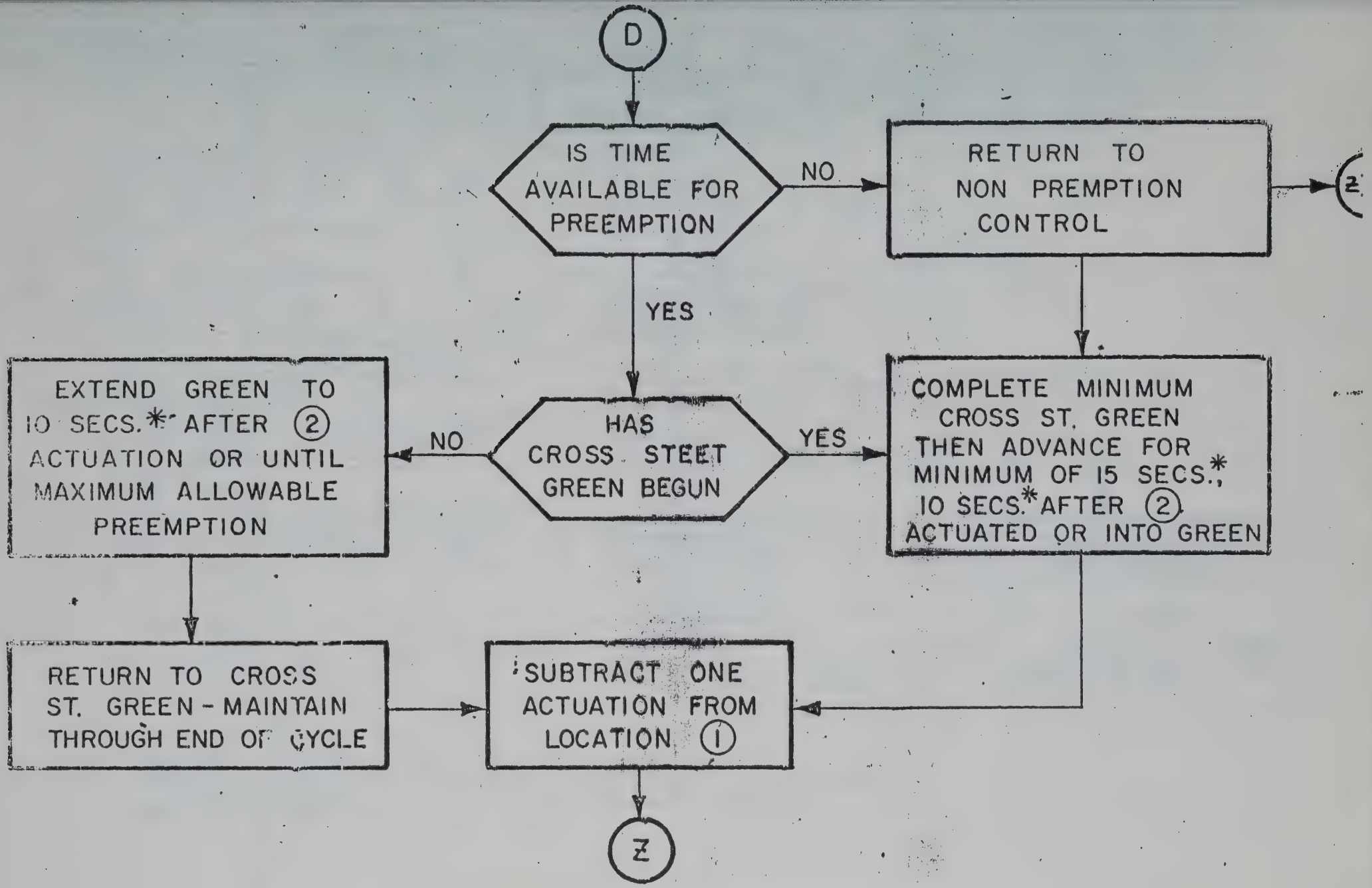
Routine G is used only when the congestion time limit is exceeded. As in Routine E, it first determines if the bus will get a green extension or green advance. In the green extension, preemption can be extended to the maximum allowable preemption while still maintaining a minimum 15 second phase for the cross street. In green advance, the maximum preemption will continue into the green of the following cycle.

STRATEGY 1A-

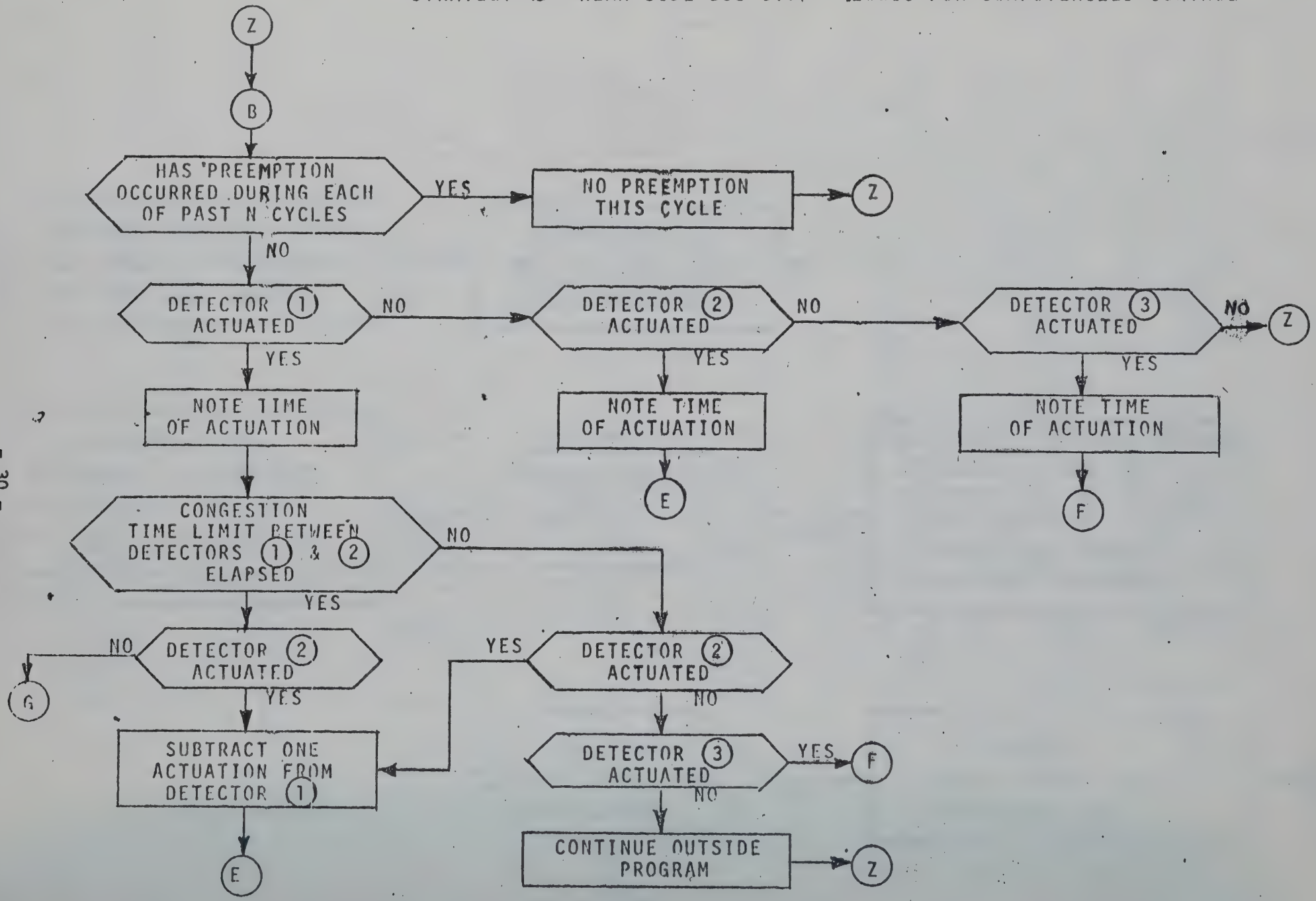
FAR SIDE BUS STOP - LOGIC FOR COMPUTERIZED CONTROL

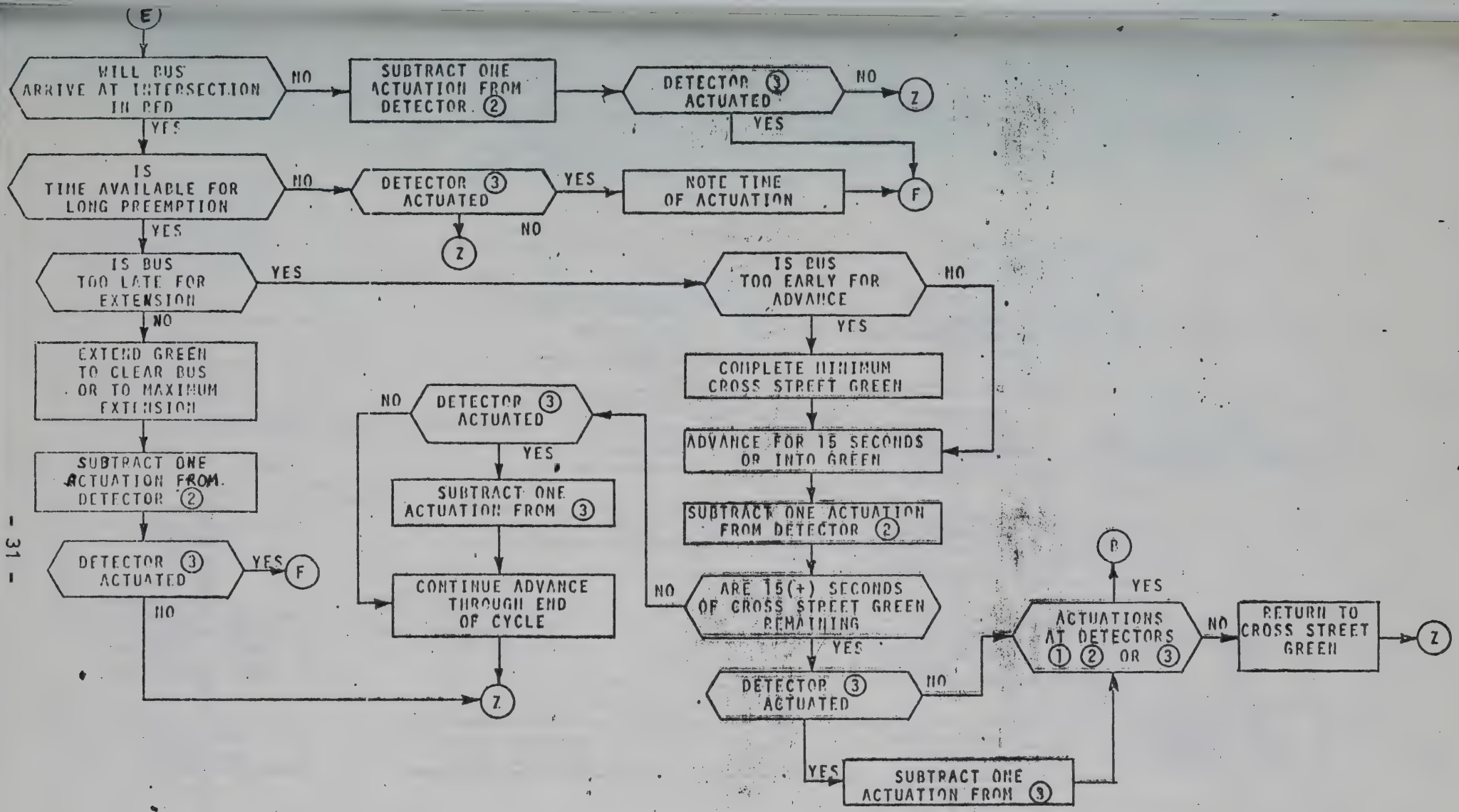


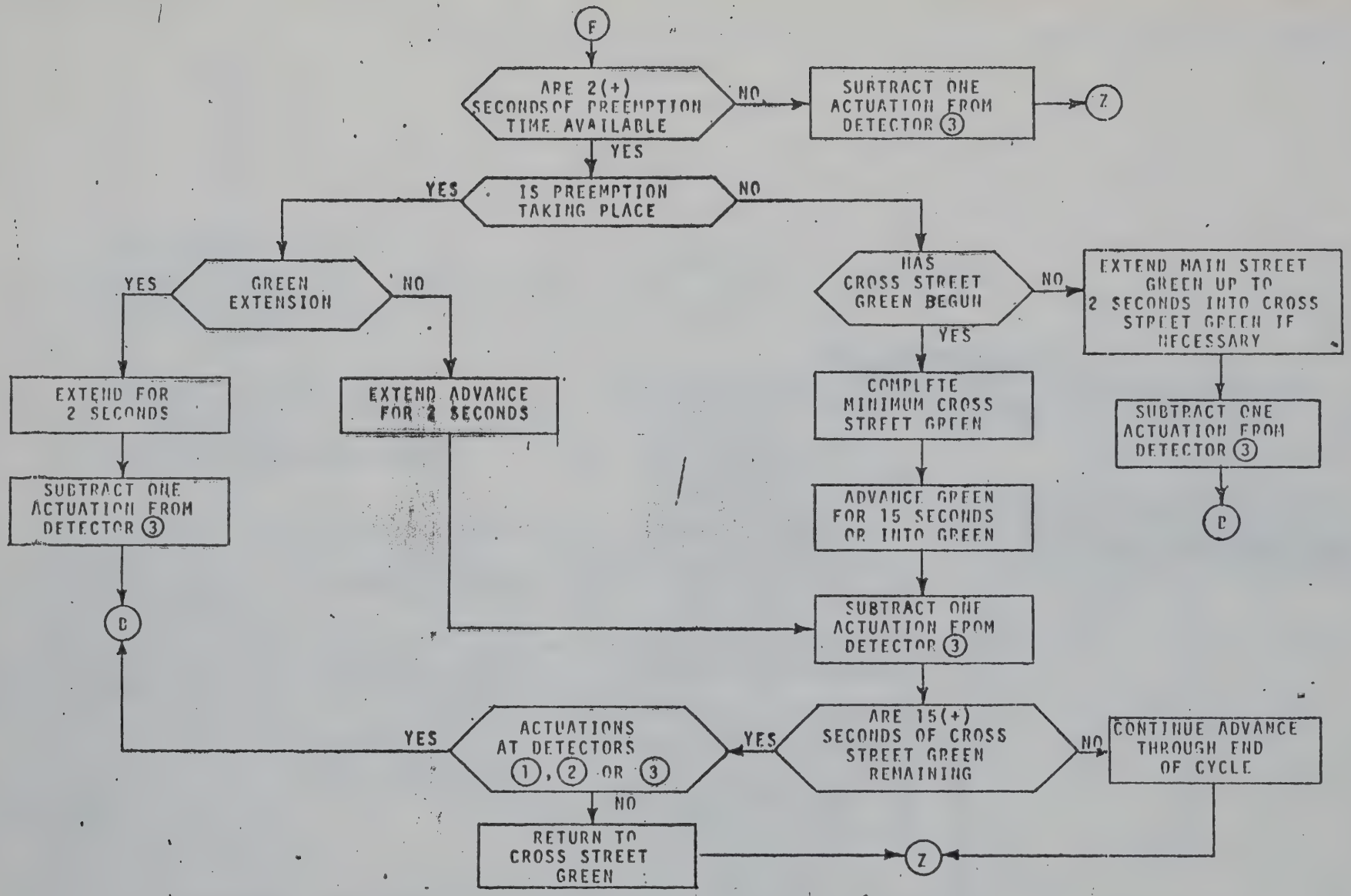

C
WILL BUS ARRIVE AT INTERSECTION IN RED
NO
SUBTRACT ONE ACTUATION FROM DETECTOR (2)
Z
YES
IS TIME AVAILABLE FOR PREEMTION *
NO
RETURN TO NON PREEMPT CONTROL
Z
YES
IS BUS TOO LATE FOR EXTENSION
YES
IS BUS TOO EARLY FOR ADVANCE
NO
NO
YES
EXTEND GREEN * TO CLEAR BUS OR TO MAX. EXT.
COMPLETE MINIMUM CROSS ST. GREEN *
SUBTRACT ONE ACTUATION FROM DETECTOR (2)
ADVANCE FOR *15 SECONDS OR INTO GREEN
Z
SUBTRACT ONE ACTUATION FROM DETECTOR (2)
ARE 15(+) SECONDS OF SIDE STREET GREEN * REMAINING
YES
A
NO
CONTINUE ADVANCE THROUGH END OF CYCLE
Z

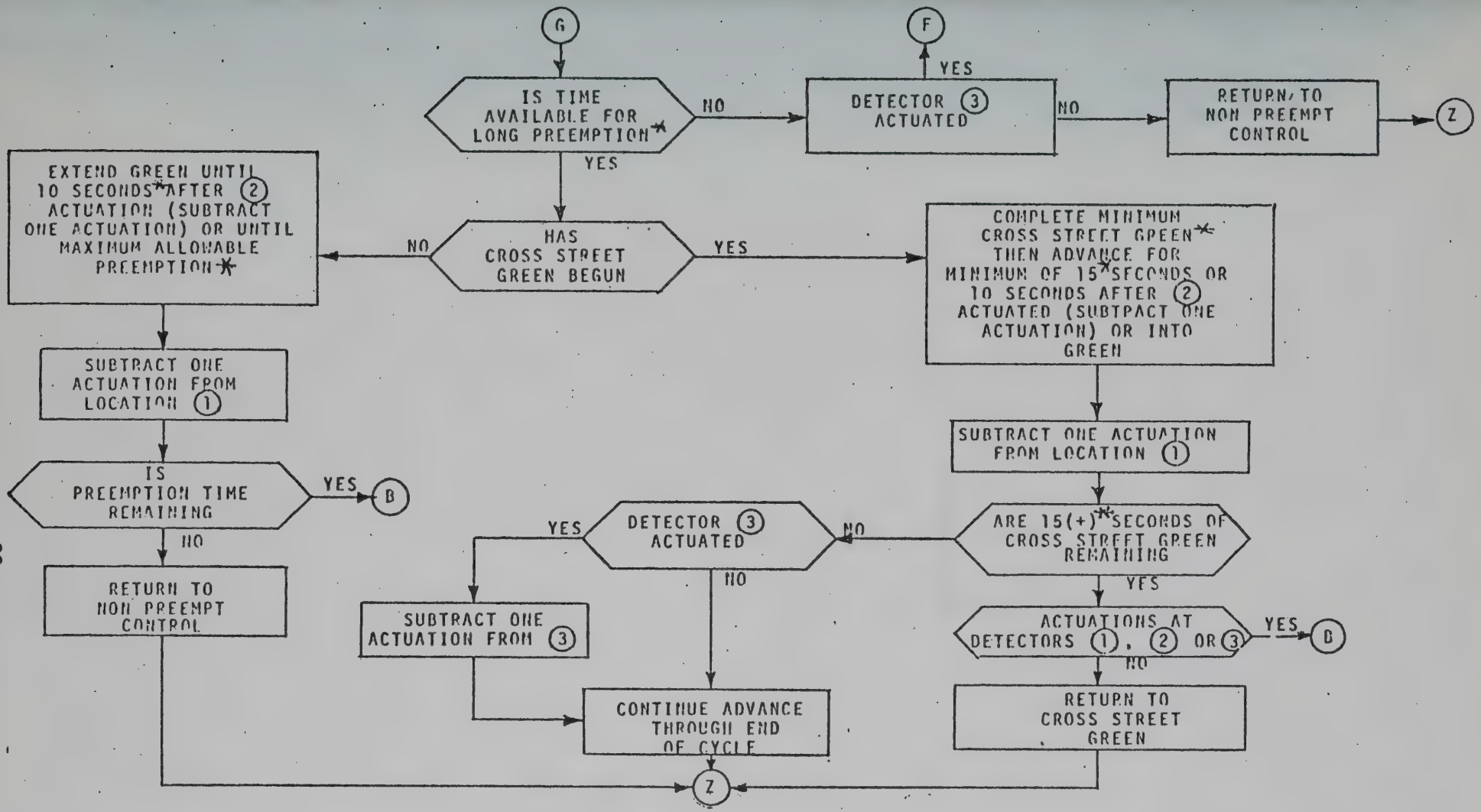

D
IS TIME AVAILABLE FOR PREEMPTION
NO
RETURN TO NON PREMPTION CONTROL
Z
YES
EXTEND GREEN TO 10 SECS.* AFTER (2) ACTUATION OR UNTIL MAXIMUM ALLOWABLE PREEMPTION
NO
HAS CROSS STEET GREEN BEGUN
YES
COMPLETE MINIMUM CROSS ST. GREEN THEN ADVANCE FOR MINIMUM OF 15 SECS.,* 10 SECS.* AFTER (2) ACTUATED OR INTO GREEN
RETURN TO CROSS ST. GREEN - MAINTAIN THROUGH END OF CYCLE
SUBTRACT ONE ACTUATION FROM LOCATION (1)
Z

STRATEGY 1B - NEAR SIDE BUS STOP - LOGIC FOR COMPUTERIZED CONTROL




E
WILL BUS ARRIVE AT INTERSECTION IN RED
NO
SUBTRACT ONE ACTUATION FROM DETECTOR (2)
DETECTOR (3) ACTUATED
NO
Z
YES
YES
IS TIME AVAILABLE FOR LONG PREEMPTION
NO
DETECTOR (3) ACTUATED
YES
NOTE TIME OF ACTUATION
F
NO
Z
YES
IS BUS TOO LATE FOR EXTENSION
YES
IS BUS TOO EARLY FOR ADVANCE
NO
NO
YES
EXTEND GREEN TO CLEAR BUS OR TO MAXIMUM EXTENSION
COMPLETE MINIMUM CROSS STREET GREEN
NO
DETECTOR (3) ACTUATED
ADVANCE FOR 15 SECONDS OR INTO GREEN
YES
SUBTRACT ONE ACTUATION FROM DETECTOR (2)
SUBTRACT ONE ACTUATION FROM (3)
SUBTRACT ONE ACTUATION FROM DETECTOR (2)
DETECTOR (3) ACTUATED
YES
F
CONTINUE ADVANCE THROUGH END OF CYCLE
NO
ARE 15(+) SECONDS OF CROSS STREET GREEN REMAINING
P
YES
ACTUATIONS AT DETECTORS (1) (2) OR (3)
NO
RETURN TO CROSS STREET GREEN
Z
NO
YES
DETECTOR (3) ACTUATED
YES
SUBTRACT ONE ACTUATION FROM (3)
Z


F
ARE 2(+) SECONDS OF PREEMPTION TIME AVAILABLE
NO
SUBTRACT ONE ACTUATION FROM DETECTOR (3)
Z
YES
YES
IS PREEMPTION TAKING PLACE
NO
YES
GREEN EXTENSION
NO
HAS CROSS STREET GREEN BEGUN
NO
EXTEND MAIN STREET GREEN UP TO 2 SECONDS INTO CROSS STREET GREEN IF NECESSARY
YES
EXTEND FOR 2 SECONDS
EXTEND ADVANCE FOR 2 SECONDS
COMPLETE MINIMUM CROSS STREET GREEN
SUBTRACT ONE ACTUATION FROM DETECTOR (3)
SUBTRACT ONE ACTUATION FROM DETECTOR (3)
ADVANCE GREEN FOR 15 SECONDS OR INTO GREEN
P
B
SUBTRACT ONE ACTUATION FROM DETECTOR (3)
YES
ACTUATIONS AT DETECTORS (1), (2) OR (3)
YES
ARE 15(+) SECONDS OF CROSS STREET GREEN REMAINING
NO
CONTINUE ADVANCE THROUGH END OF CYCLE
NO
RETURN TO CROSS STREET GREEN
Z


G
IS TIME AVAILABLE FOR LONG PREEMPTION*
NO
YES
F
YES
DETECTOR (3) ACTUATED
NO
RETURN TO NON PREEMPT CONTROL
Z
EXTEND GREEN UNTIL 10 SECONDS* AFTER (2) ACTUATION (SUBTRACT ONE ACTUATION) OR UNTIL MAXIMUM ALLOWABLE PREEMPTION*
NO
HAS CROSS STREET GREEN BEGUN
YES
COMPLETE MINIMUM CROSS STREET GREEN* THEN ADVANCE FOR MINIMUM OF 15* SECONDS OR 10 SECONDS AFTER (2) ACTUATED (SUBTRACT ONE ACTUATION) OR INTO GREEN
SUBTRACT ONE ACTUATION FROM LOCATION (1)
IS PREEMPTION TIME REMAINING
YES
B
NO
RETURN TO NON PREEMPT CONTROL
SUBTRACT ONE ACTUATION FROM LOCATION (1)
ARE 15(+)* SECONDS OF CROSS STREET GREEN REMAINING
NO
YES
DETECTOR (3) ACTUATED
YES
NO
SUBTRACT ONE ACTUATION FROM (3)
ACTUATIONS AT DETECTORS (1), (2) OR (3)
YES
B
NO
CONTINUE ADVANCE THROUGH END OF CYCLE
RETURN TO CROSS STREET GREEN
Z

APPENDIX B

INPUT

PROCEDURES AND REQUIREMENTS

3.0 PROCEDURES AND REQUIREMENTS

3.1 Initiation

The system enhancements to incorporate the bus preemption strategies are directly incorporated into the NETSIM model. The existence of bus preemption is established by the inclusion of bus preemption data cards into the input deck. The absence of these cards will cause a run without preemption to be simulated. Thus, there are no unique procedures associated with the selection of bus preemption in the NETSIM model. The bus preemption logic is embedded in the code. It is only necessary to insert the bus preemption data cards into the normal data deck in order to execute the bus preemption.

3.2 Input

The input data is normally keypunched on cards. Once a basic network is defined, then it will only be necessary to alter parameters on the cards when changes are required. It is possible that routes may be added or deleted, the bus stop and/or detectors moved, and the timing changed. In any of these cases, it will be necessary to change some of the parameters on the bus preemption cards.

3.2.1 Input Format

There are five new card types defined for the bus preemption logic. These new card types supplement the standard NETSIM data card deck. Each variable on each card will be discussed in this section. Each of the new cards is described in the following discussion. The first new card is the bus priority control card, card type 35.

Bus Priority Control Card — Type 35

The bus priority control card contains the global default values for the bus preemption logic. All the parameters on the card are integers. Only items 15-19 are used by the simulation. None of the global variables or the general parameters are used. However, it will be necessary to put in data for items 1-8 or to accept the default values by placing negative values into these fields. Items 16-19 relate to timing limits in subroutines BPS1 and BPS2.

Entry	Columns	Description
1	1-4	Minimum cycles length, MINC, in seconds
2	5-8	Maximum cycle length, MAXC, in seconds
3	9-11	Minimum interval duration, MININT, in seconds
4	12-14	Maximum interval duration, MAXINT, in seconds
5	15-17	Minimum green extension, MINEX, in seconds
6	18-20	Maximum green extension, MAXEX, in seconds
7	21-23	Minimum green advance MINADV, in seconds
8	24-26	Maximum green advance, MAXADV, in seconds
9	27-31	General parameter number 1
10	32-36	General parameter number 2
11	37-41	General parameter number 3
12	42-46	General parameter number 4
13	47-51	General parameter number 5
14	52-56	General parameter number 6
15	57-59	Congestion time limit, MAXTIM, in seconds

16	60-62	Detector 1 preemption time, LEXT, in seconds
17	63-65	Cutoff time, LCUT, in seconds
18	66-68	Target time for initial extensions, LADV1, in seconds
19	69-71	Target time for the add-on extensions, LADV2, in seconds
20	79-80	Card type 35

Entry	Discussion
15	This item is MAXTIM, used in subroutine BPSA. This was previously set by a data statement.
16	This item, LEXT, indicates the time that the extension will be reduced to after a bus congestion reaches the downstream detector. The default value is 10 seconds.
17	This item, LCUT, defines the cutoff point to determine if the advance or extension is to be granted. Whenever the green time remaining is greater than LCUT seconds, or the red time is less than LCUT seconds, no preemption will be granted. LCUT $\leq$ LADV1, Default value is 15 seconds.
18	This item LADV1, defines the target extension time for initial preemptions, The default value is 15 seconds.
19	This item, LADV2, defines the target extension time for add-on extensions. The default value is 15 seconds.
20	Card type. This field must contain the value "35".

Bus Surveillance Card -- Type 36

The bus surveillance card defines the detectors on each link. A separate card is required for each link. Up to nine detectors per link are allowed. They must be arranged sequentially with Detector 1, the most downstream detector.

Entry	Columns	Description
1	1-3	NV, upstream node i of link (ij)
2	3-6	ND, downstream node j of link (ij)
3	7-11	LEDT1, distance in feet from the detector to the downstream node
4	12-13	LND1, lane in which the detector is located. A value of 9 indicates the detector is in all lanes.
5	14-18	LEDT2, same as item 3, for the second detector
6	19-20	LND2, same as item 4, for the second detector
7-8	21-25,26,27	Same as items 3 and 4, for the third detector
9-10	28-32,33,34	Same as items 3 and 4, for the fourth detector
11-12	35-39,40,41	Same as items 3 and 4, for the fifth detector
13-14	42-46,47-48	Same as items 3 and 5, for the sixth detector
15-16	49-53,54-55	Same as items 3 and 4, for the seventh detector
17-18	56-60,61,62	Same as items 3 and 4, for the eighth detector
19-20	63-67,68,69	Same as items 3 and 4, for the ninth detector
21	79,80	The value 36 must be punched to define card type 36

Entry	Discussion
1,2	These two entries are necessary to define the link on which the detectors are located. Link (ij) is defined by the upstream and downstream nodes.
3,4	These two integer items define the Detector 1. Entry 3 is the distance of the detector from the downstream end of the link. Entry 4 gives the lane in which the detector is located.
5,6	These entries define Detector 2.
7,8	These entries define Detector 3.
9,10	These entries define Detector 4.
11,12	These entries define Detector 5.
13,14	These entries define Detector 6.
15,16	These entries define Detector 7.
17,18	These entries define Detector 8.
19,20	These entries define Detector 9.
21	Card type. This field must contain the value 36.

It is noted that the far side bus preemption logic requires two detectors per link. The near side bus preemption logic requires three detectors per link.

The detector data is stored into IDET and IDETEC in Common/B1/. Both of these arrays are dimensioned with 40 elements each. The detector location is stored in the IDETEC array and IDET points to the location of the first (most downstream detector on the link). IDEL(L) is indexed by internal link number. Its output is an index which locates the most downstream detector on link L. IDETEC contains the index of the next bus detector on this link in addition to its position and lane. The input processing for card type 36 first establishes the internal link number L for the input link (I,J). It then tests that the position of the detectors are not beyond the length of the link and that they are sequential. If they are, the next available location in IDETEC is found and this index stored

in IDET(L). The lane and location of the detector is stored in IDETEC. If another detector is defined on this link then the next available location IDETEC is stored in the previous IDETEC locations. In this manner, a list type structure is established with IDGT(L) pointing to the first element in the list and subsequent entries pointing to the next. The last detector in the string (most upstream) contains a zero as the address of the next detector.

Bus Trace Card -- Card Type 37

This card is used to define the bus trace options which are planned for the bus preemption strategies. However, they are not implemented, so that nothing on this card is currently used. However, the data on this card is read, stored, and printed out.

Entry	Columns	Description
1	1-3	IR 1--number of bus route to be traced
2	4-5	IT1--trace option #1: no = 0; yes = 1
3	6-7	IT2--trace option #2: no = 0; yes = 1
4	8-9	IT3--trace option #3: no = 0; yes = 1
	10-15	Not used
5,6,7,8	16-30	Same as items 1-4 for second bus route
9,10,11,12	31-45	Same as items 1-4 for third bus route
13,14,15,16	46-60	Same as items 1-4 for fourth bus route
17,18,19,20	61-75	Same as items 1-4 for fifth bus route
21	79,80	The value 37 must be punched to define the card type 37.

BPR Node Parameter Card -- Type 38

This card contains these parameters which are unique to a node. The majority of the items on this card are not used. Only the node, N, and the bus preemption strategy, NBP(N), at this node need be defined. The inclusion of the bus preemption type on the node card restricts the logic to one bus preemption type per node even though the remaining logic could handle different types at the same node.

Entry	Columns	Description
1	1-3	N node number
2	4-5	NBP(N) bus preemption strategy at this node; NBP(N)=1 is the far-side strategy; =2 the near-side strategy
3	6-8	INTER(N) -- not used
4,5,6	11-15,16-20, 21,25	NPI(N) -- not used
7	79,80	The card type, 38, must be punched in the columns

BPR Link Parameter Card -- Type 39

The card contains the bus preemption parameters unique to each link. Although the card contains a number of parameters, the current versions of the near-side and far-side logic only utilize two parameters, MINEX(L) and MAXEX(L). The other parameters are read in, processed, stored, and printed out, but are not used by the simulator.

Entry	Columns	Description
1	1-3	The upstream node i of link (i,j), ND
2	4-6	The downstream node j of link (i,j), ND
3	7-9	MININT(L), unused
4	10-12	MAXINT(L), unused
5	13-15	MINEX(L): the minimum green extension, in seconds
6	16-18	MAXEX(L): the maximum green extension, in seconds
7	19-21	MINADV(L), not used
8	22-24	MAXADV(L), not used
9	29-33	LP1(L), not used
10	34-38	LP2(L), not used
11	39-43	LP3(L), not used
12	79-80	Card type 39 punched in here

Entry	Discussion
1,2	Identify the link being processed, in terms of the upstream and downstream nodes.
3,4	Not used.
5	MINEX(L) defines the minimum extension. This is used by the near-side bus preemption logic to establish the "short preemption" for the bus clearance detector.
6	MAXEX(L) defines the maximum extension time which will be added to the normal preemption. This is used by both the far-side and the near-side bus preemption logic. The value represents the overall sum of preemption times and defines the upper limit for the overall preemptions granted to one phase.

APPENDIX C

OPERATOR AND TIMER INSTRUCTIONS FOR FIELD STUDY

7717 BUS SIGNAL PREEMPTION

OPERATOR INSTRUCTIONS

Duties

The operator will activate manual control and take control of the intersection following a call for bus preemption from the detector. He will return the signal to automatic control after preemption is completed.

Equipment

Tape recorder

Walkie-Talkie

Stop watch

Procedure

1) After receiving a call for bus preemption from "detector," manual control will be activated.

2) The schedule for signal timing as set out in the instructions entitled "Signal Timing" will be adhered to. All intervals implemented under manual control should be timed by stop watch.

3) The operator will announce the beginning and end of periods of manual control. He should also announce the time of day at frequent intervals.

4) All points of interval change should be announced.

5) When no preemption is in progress, automatic control will be maintained, and the push button for manual control left on the controller door.

7717 BUS SIGNAL PREEMPTION

SIGNAL TIMING

A certain risk is involved to the public any time that manual control of a traffic signal is implemented. Since this risk cannot be avoided completely in this case (manual control being necessary in order to simulate signal preemption in the field), it was decided to minimize this risk as much as possible by adhering to the signal timing ranges already in use during normal semi-actuated operation of the signal under automatic control.

The timing schedule presently installed at Route 31 and Ewingville Road is as follows:

	70 Second Background Cycle					
	Ped. Time	Green	Yellow	All Red	Red	Offset
Route 31	-	53-36	5	0	12-29	35
Ewingville Road	12	7-24	3	2	58-41	

Since the traffic signal controller can be easily switched between automatic control and manual control as appropriate, manual control will only be implemented when a bus preemption has been called. At all other times, automatic control will be in force. When the preemption has been completed, the signal will be returned to automatic control in main street (Route 31) green.

Consultation with personnel from the Bureaus of Traffic Engineering and Electrical Operations revealed that most of the risk to the public under manual control results from shortening of the clearance intervals. To minimize the risk the clearance intervals will be maintained under manual control as follows:

1) Route 31 - Not less than 5 seconds of amber as per automatic timing.
2) Ewingville Road - not less than 3 seconds of amber followed by not less than 2 seconds of all red as per automatic timing.

Another area of risk to the public involves giving a very short green interval to any approach. The greatest risk of this happening in this case is in regard to the side street (Ewingville Road) approach. Under automatic control the normal range for the green interval on Ewingville Road is 7-24 seconds. Therefore, once the clearance interval has begun on Route 31, the green interval on Ewingville Road will be maintained under manual control as follows:

1) Not less than 7 seconds of green time will be provided to Ewingville Road before a return to Route 31 green can be made. (In most cases, 12 seconds will be the effective minimum since 7 seconds will only be used when no cars are waiting on the two side street approaches.)
2) Not more than 24 seconds of green time will be provided to Ewingville Road before a return to Route 31 green is made.

In this case, the risk of a very short green interval occurring on Route 31 is very small since buses on Ewingville Road will not be given preemptions. However, the normal range for the green indication on Route 31 (36-53 seconds) under automatic control will be adhered to under manual control. Therefore, once the clearance interval has begun on Ewingville Road, the green interval will be maintained under manual control as follows:

- not less than 36 seconds of green time will be provided to Route 31 before a return to Ewingville Road green is made.

7717 BUS SIGNAL PREEMPTION

TIMER INSTRUCTIONS

Duties

The timer will keep track of and record the beginning and end of all intervals during periods of manual control of the intersection. During automatic control he need only record the beginning of main street green and main street red.

Equipment

Tape Recorder

Clipboard

Timer sheet and pencil

Procedure

1) Start tape recorder at beginning of study period (4 p.m.).
2) At fairly frequent intervals, announce time of day.
3) Announce beginning and end of manual control periods.
4) Announce beginning of interval by simply stating which interval it is; i.e., "amber" for clearance interval followed by "red" for end of clearance interval.
5) After end of clearance interval announce status of green; i.e., "green on Route 31."
6) The timer sheet can be used to backup the tape recorder, if necessary. However, extra tapes will be available.

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Volume I: Technical Report

Volume II: Program Documentation for UTCS-1 Network Simulation Model, Part I

Volume III: Part II

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